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Features of Anomalous Small of Strain Coefficient

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The analysis of one of the neglected problem of strain effect – causes observation anomalous small longitudinal strain coefficient (γ_l). It is concluded that the value of $\gamma_l < 3$ units will take place in the case where in the quasi elastic or plastic deformation Poisson coefficient is more than 0.5. Discussed possible reasons for this increase.

Keywords: Strain effect, Poisson coefficient, Gruneisen constant, Debay temterature, Anomalous small strain coefficient.

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1. INTRODUCTION

In works by G.Kuczynski [1], R.Parker and A.Krinsky [2], Z.Meiksin and Hudzinski [3] have laid the theoretical and experimental investigate of the strain effect in the metal wires and thin films. For today investigated almost all aspects of this effectIn particular, by taking into account the contribution of surface and grain-boundary electron scattering [4] in the coefficient of and transverse strain for one-layer films. We proposed a phenomenological model [5] for the longitudinal strain coefficient, which takes into account the dependence of strain not only mean free path of electrons (λ_0) in the bulk of crystal grains, but the parameter of specular reflection from external surface film, transmission coefficients of grain boundaries and interfaces in the multilayer film systems. Testing of this model has given satisfactorily results. Along with the studies of external and internal classical size effects in strain effect for one-layer films and multilayers has gained significant experimental material about film alloys Ni-Cr [6, 7], Ni-Co [8], Ni-Fe [9, 10], heterogeneous [11, 12] and diamond and diamond like [13-16] materials.

Along with research of the strain effects focuses on mechanical properties and plastic deformation mechanisms of the free films and films on the substrate. It has been clearly established that the mechanical properties (Young's modulus, strength, strain at which the transition to plasticity) fine-dispersed films and bulk materials are quite different. In the case of coarse-dispersed films mechanical properties, with the exception of plasticity, does not differ significantly.

Systematic study of size effect in plasticity of films Cu, Al and Au (thickness from 0.2 to 1 μm) and multilayers of Cu / Ni presented in works [17-19]. These studies are important for the correct interpretation of the results for strain effect, because the value γ_l, it is completely determined by the type of deformation – elastic, quasi elastic or plastic. According to different authors deformation transition from elastic to plastic deformation (ε_{tr}) for films has a values: 0.10-0.20 (Cr); 0.25-0.52 (Pd); 0.30-0.40 (Fe / Cr); 0.25 (Cu / Cr) and 0.48 % (Pd / Fe).

Analyzing a many results for strain effect, we conclude that at present remains unclear cause of thin films anomalous small values γ_l under which we mean all values γ_l less than a certain limit value strain coefficient γ_l^b, which corresponds to the Poisson coefficient of film $\mu_f = 0.5$. Definitely estimate the value γ_l^b impossible, but approximate its value within $\gamma_l^b \cong (1 + 2\mu_f) \div 3$ units.

Because preliminary research results of strain effect in films Pd, Ag and others and the results of work [21] for films Pt indicate anomalous small value (γ_l), than the aim of this work was to detailed study of strain effect in Pd and Pt films and analyzing the future of anomalous strain coefficient.

2. TECHNIQUE OF EXPERIMENT

Thin Pd and Pt films were obtained by thermoresistive evaporation in a vacuum ~ 10^{-4} Pa at substrate temperature $T_s = 300$ K.

Tensoresistive properties were investigated for five-seven deformation cycles "loading-unloading" at strains intervals $\Delta\varepsilon_{l1} = (0\text{-}1)$ % and $\Delta\varepsilon_{l2} = (0\text{-}2)$ % by standard method.

Average strain coefficient (γ_l) and momentary strain coefficient (γ_{lm}) defined by the ratio $\gamma_l = \frac{1}{R_0}\frac{\Delta R}{\Delta\varepsilon_l}$ and $\gamma_{lm} = \frac{1}{R_i}\frac{dR_i}{d\varepsilon_{li}}$, respectively, where R_0 – initial electrical resistance in the longitudinal deformation, R_i and dR_i – film resistance at the beginning of the interval $d\varepsilon_{li}$ and its change with increasing longitudinal strain on $d\varepsilon_{li}$. Value γ_l was calculated as the slope of dependence

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$\Delta R / R_0$ versus ε_l, and averaging in the interval $\Delta\varepsilon_l$ value γ_{lm} which is calculated based graphical derivation of dependence $d\ln R_i$ by ε_l. Both procedures give the same value γ_l. Measurement technique γ_l and γ_{lm} is set out in more detail in article [21].

Electronografic and structural studies were carried out using a device with a high a resolution ПЕМ-125К (firm "SELMI").

3. RESULTS AND DISCUSSION

Pd and Pt films after condensation have nanocrystalline structure and the fcc-lattice with a lattice parameter nearest to the value for the bulk samples. Fig. 1 illustrates a typical deformation dependence R i $\Delta R / R_0$ versus ε_l for the interval deformation (0-1) %. From these results it follows that the value γ_l depends on the type of strain cycle and from V-VII cycles saturates. Note that the thin film Pd and Pt, as well as other noble metals, are characterized by relatively wide intervals plastic or quasi-elastic deformation. This is evidenced by the linear nature of the dependence R and $\Delta R / R_0$ versus ε_l for II-VII cycles (Fig. 1). On Fig. 2 shows the size dependence of the average strain coefficient for the Pd and Pt films.

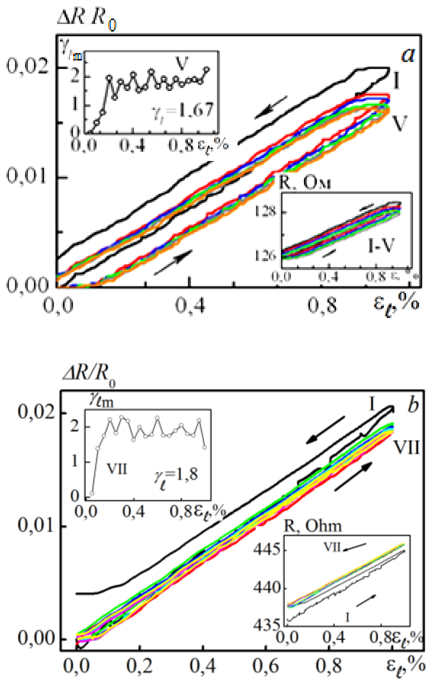

Fig. 1 – Strain dependence R and $\Delta R / R_0$ versus ε_l for Pd (a) and Pt (b) films. The inset – strain dependence of the momentary strain coefficient and R versus ε_l

Classical theory of strain effect in bulk samples developed in article [1] and in the most general form longitudinal strain coefficient is written as:

$$\gamma_l \equiv \frac{d\ln R}{d\varepsilon_l} = \frac{d\ln\rho}{d\varepsilon_l} + \left(1+\mu_f+\mu_f^{'}\right) \cong \frac{d\ln\rho}{d\varepsilon_l} + \left(1+2\mu_f\right), \quad (1)$$

where R and ρ – resistance and resistivity; $d\varepsilon_l = d\ln l$ – longitudinal deformation (l – length of sample) and $\mu_f^{'} = \mu_f \cdot \dfrac{1-\mu_s}{1-\mu_f} \cong \mu_f$ (μ_s – Poisson coefficient of substrate).

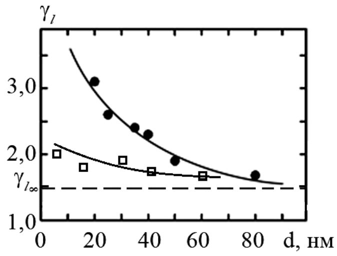

Fig. 2 – Size dependence of the average strain coefficient for Pd (□) and Pt (●) films

The first term γ_l^{ρ} is associated with internal electronic properties of the material, and the second term - a so-called geometric factor that is associated with the change of geometrical dimensions of the sample. Assuming that $\rho \approx n^{-1}\lambda_0^{-1}$ (n – effective concentration of free electrons), the author [1] received the ratio γ_l^{ρ}:

$$\gamma_l^{\rho} = \frac{d\ln\rho}{d\varepsilon_l} = -\left(\frac{\ln\lambda_0}{d\varepsilon_l} + \frac{d\ln n}{d\varepsilon_l}\right) = \frac{2d\ln\Theta_D}{d\varepsilon_l} + 1, \quad (2)$$

where Θ_D – Debye temperature at the film.

Considering that the $\dfrac{d\ln\Theta_D}{d\ln V} = \gamma$ (V – volume, γ – Gruneisen constant), ratio (2) can be rewritten as:

$$\gamma_l^{\rho} = 1 + 2\gamma\left(1-2\mu_f\right) = 1 + \eta_{\lambda_0 l}, \quad (2')$$

and ratio (1) converted to the form:

$$\gamma_l = 1 + (2\gamma - 4\mu_f\gamma) + \left(1+2\mu_f\right), \quad (3)$$

where $\eta_{\lambda_0 l} = -\dfrac{d\ln\lambda_0}{d\varepsilon}$ - strain coefficient of λ_0.

From ratio (3) it follows that $\gamma_l^{b} = \lim\gamma_l = 2\left(1+2\mu_f\right) \approx 3$ (although the condition $\gamma_l^{\rho} = 0$ value is $\gamma_l^{b} = 2$). The authors [23] have analyzed this issue for thin films in the framework of the Fuch-Sondgeimer (FS) in the limiting case of small thicknesses ($\dfrac{d}{\lambda_0} \cong 1$, d – film thickness). They got value for γ_l provided at the condition $\rho \cong \lambda_0^{-1} n^{-\frac{3}{2}}$:

$$\gamma_l = 2\left(\frac{5}{6} + \mu_f\right) + \left(2\gamma - 4\alpha\mu_f\right), \quad (4)$$

that the μ_f =0.5 gives the value $\gamma_l^{b} = 2.7$.

Our analysis shows that the cause of anomalously small values γ_l of the gauge can be explained within the framework of the ratio (3) or (4).Calculate the value μ_f for different values γ_l at the fixed values of Gruneisen constant (Fig. 1) indicate that anomaly small size γ_l occur at a value $\mu_f > 0.4$, i.e. in the quasi- and plastic deformation. Despite the fact that the strain ε_{tr} was measured with sufficient accuracy based on strain diagram, it cannot be established on the basis of the size dependence γ_l from d, and since ε_{tr} size dependent value.

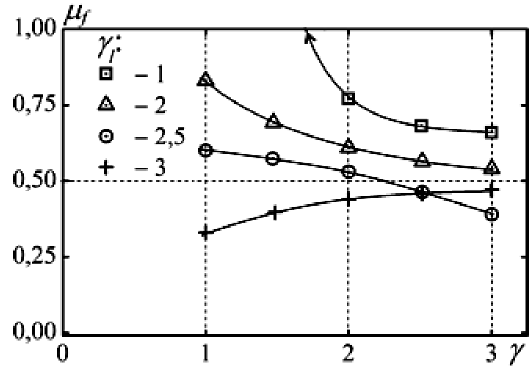

Fig. 3 – Calculated values μ_f based on equation (4) for different values γ and γ_l. From article [24]

This may have this could lead to the fact that the size dependence γ_l versus d [2, 9, 10, 16, 21] were obtained in the elastic deformation (relatively small thickness) or quasy elastic and/or plastic deformation (thick films).

From the relations (3)-(5), it follows that the value γ_l is completely determined terms ($2\gamma - 4\mu_f\gamma$): at $\mu_f < 0{,}5$ it gives positive contribution to the value γ_l, while for large μ_f (more than 0,5) – from capacious contribution. From Fig. 1 shows that when $\gamma_l < 2.5$-3.0 units, then μ_f has a value greater than 0.5, i.e. the deformation of the film takes place in the area of quasy elasticity or plasticity. The curves for $\gamma_l = 1$; 2 and 2.5 indicates that explain the reason for anomalously small values γ_l just based on the idea increasing μ_f, not because you have to allow for an increase in μ_f to a value greater than $\gamma_l = 1$. Thus, in this case, the increased μ_f must increase was Gruneisen constant.

Really, when you consider that the minimum wavelength phonons $\lambda_{\min} = 2a$ (a – lattice parameter), then change Θ_D for the strain longitudinal phonon spectrum mode decrease the equation:

$$\Delta\Theta_D^x = \frac{hv_{ph}}{2k_B}\cdot\left(\frac{1}{a\cdot(1+\mu_f\varepsilon_l)} - \frac{1}{a}\right) = \frac{v_{ph}}{2k_B a}\cdot\left(\frac{\mu_f\varepsilon_l}{1+\mu_f\varepsilon_l}\right)$$

and slightly increased in the case of transverse oscillation modes:

$$\Delta\Theta_D^{y,z} = \frac{hv_{ph}}{2k_B a}\cdot\left(\frac{\mu_f\varepsilon_l}{1-\mu_f\varepsilon_l}\right),$$

where v_{ph} – the phase velocity; k_B – the Boltzmann constant.

It is known that in thin films or small particles we observe a decrease Θ_D (see, for example, [1]), which increases the mean square displacement of atoms as $\overline{u^2} \cong \left(\frac{T}{\Theta_D}\right)^2$. Increase $\overline{u^2}$ determines some effective increase $\mu_f' = -\frac{d\ln d}{d\ln l}$. Qualitative considerations indicate that the longitudinal deformation film value Θ_D will also generally decrease, although strain causes a slight increase. Thus, in all film materials value μ_f must be somewhat overpriced compared to bulk samples.

Another mechanism an increase μ_f' is associated with in some reduction in thickness $\Delta d'$ due to diffusion of surface atoms at grain boundaries, which during deformation $\Delta\varepsilon_{l,t} > 0$ width will increase. The smoothing relief of film surface will cause an additional contribution $\Delta\mu_f'$ in value μ_f'.

And, finally, may also result in a decrease γ of the reduction $(2\gamma - 4\mu_f\gamma)$ plugin that causes a change γ_l downward.

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REFERENCES

1. G.C. Kuczynski, *Phys. Rev.* **94**, 61 (1954).
2. R.L. Parker, A. Krinsky, *J.Appl. Phys.* **34**, 2700 (1963).
3. Z.H. Meiksin, R.A. Hudzinski, *J. Appl. Phys.* **38**, 4490 (1967).
4. C.R. Tellier, A.J. Tosser, *Size effects in thin films* (Amsterdam-Oxford-New York: ESPS: 1982).
5. O. Lasyuchenko, L. Odnodvoretz, I. Protsenko, *Cryst. Res. Technol.* **35**, 329 (2000).
6. I.H. Kazi, P.M. Wild, T.N. Moore, et al., *Thin Solid Films.* **515**, 2602 (2006).
7. M.A. Angadi, R. Whiting, *Mater. Sci. Engin. B* **7**, L1 (1990).
8. V.A. Kravchenko, V.B. Loboda, I.Yu. Protsenko. et al., *Functional Mater.* **6**, No 5, 892 (1999).
9. K. Rajanna, M.M. Nayak, *Mat. Sci. Eng. B.* **B77**, 288 (2000).
10. K.V. Tyschenko, I.Yu. Protsenko, *Mettallofiz. Nov. Tekhnol.* **34** No 7, 907 (2012).
11. M. Hrovat, D. Belavic, Z. Samardzija, et al., *J. Mater. Sci.* **36**, 2679 (2001).
12. M. Hrovat, A. Bencan, D. Belavic, et al., *Sens. Actuat. A.* **103**, 341 (2003).

13. M. Deguchi, M. Kitabatake, T. Hirao, *Diamond Relat. Mater.* **5**, 728 (1996).
14. A. Yamamoto, N. Norio, T. Takahiro, *Diamond Relat. Mater.* **16**, 1670 (2007).
15. U. Heckman, R. Bandorf, H. Gerdes, M. Lubke, S. Schabel, G. Brauer, *Procedia Chem.* **1**, 64 (2009).
16. R. Koppert, D. Goettel, O. Freitag-Weber, G. Schultes, *Solid State Sci.* **11**, 1797 (2009).
17. R.D. Emery, G.L. Povirk, *Acta Materialia.* **51**, 2067 (2003).
18. R.D. Emery, G.L. Povirk, *Acta Materialia.* **51**, 2079 (2003).
19. H.D. Espinosa, B.C. Prorok, B. Peng, *J. Appl. Phys.* **52**, 667 (2004).
20. R.C. Cammarata, T.E. Schlesinger, C. Kim, S.B. Qadri, S. Edelstein, *Appl. Phys. Lett.* **56**, 1862 (1990).
21. K.V. Tyschenko, I.M. Pazukha, T.M. Shabelnyk, I.Yu. Protsenko, *J. Nano- Electron. Phys.* **5** No 1, 01029 (2013).
22. S.I. Protsenko, D.V. Velykodnyi, V.A. Keraj, M.S. Desai, C.J. Panchal, I.Yu. Protsenko, *J.Mater. Sci.* **44**, 4905 (2009).
23. B.K. Sharma, N. Jain, R. Srivastava, *Helvetica Phys. Acta*, **56**, 1093 (1983).
24. I.Yu. Protsenko, L.V. Odnodvorets, K.V. Tyschenko, M.O. Shumakova, *JMET* (2011). [in Press].